MAC-U-Vision: An Application for Progressive Training for Patients with Age-Related Macular Degeneration[1]

by

Alan Tepoxtecatl, Crystal Yang, Max Sehaumpai

Final Report
CSc 59866 Senior Design/Capstone II

Zhigang Zhu, Ph.D.
Herbert G. Kayser Professor of Computer Science

William H. Seiple, Ph.D.
Chief Research Officer, Lighthouse Guild

[1] Many writing contents in this report are different from the ones in the URTC mansucript due to time sensitivity.

Abstract (0)

Age-related macular degeneration (AMD) is a disease that, in multiple stages, causes damage to the macular leading to gradual and non-reversible loss of central vision and, in certain cases, legal blindness. It is the leading cause of vision loss for adults aged 60 and older. As of 2019, 19.8 million people in the United States had a form of AMD. Currently, there exist many technologies that provide assistance to those with visual impairment, but most of these works are aimed at helping those who are already blind. Therefore, we propose and implemented an application for progressive training for AMD patients that tackles (1) how to enhance the livelihood of patients at the current stage of AMD and (2) how to prepare patients for more vision loss that may occur in the future as they proceed to the next stage. We design a solution that is divided into several levels, each corresponding to a stage of AMD. It follows that our application is not only able to address patients in any stage of the disease but it will also remain to offer different and unique features as the disease progresses. This makes our application a comprehensive platform for AMD patients.

Keywords – *macular degeneration, augmented reality, assistive technology, eye movement training, oculomotor control training, low-vision, low-vision rehabilitation, blind, visual impairment.*

Introduction (1)

The leading cause of vision loss for adults aged 60 and older is age-related macular degeneration (AMD). AMD has been estimated to affect one in three individuals aged older than 75 and one in 30 individuals older than 52 years and, in a recent study in 2019, up to 19.8 million people (12.6%) aged 40 and older in the United States are affected by some form of AMD (Klein, 1997) (CDC). The disease and accrued vision loss remain non-reversible. Currently, there exist many technologies that aim to provide assistance to patients with visual impairment. However, most of these works are considered assistive technologies or geared toward helping those who are already blind. Many technologies designed for AMD patients are also expensive and unable to remain beneficial to patients once the vision loss increases as the disease progresses.

In this paper, we propose and implemented a comprehensive application, MAC-U-Vision, that is specifically tailored to help AMD patients starting from the time of diagnosis to every stage of the disease. MAC-U-Vision is a mobile/tablet application for progressive training for AMD patients that tackles (1) how to enhance the livelihood of patients at the current stage of AMD and (2) how to prepare patients for more vision loss that may occur in the future as they proceed to the next stage of the disease, which are the primary contributions of our work. Our platform solution is organized into several stages, each corresponding to a stage of AMD. Throughout the stages, we incorporated key features such as augmented reality (AR), eye movement and oculomotor control trainings, text-to-speech, discussion forums, referral options to related professionals, and educative and informational pages among others.

This paper is organized as followed: in section 2, we provide a brief discussion of the disease background as well as relevant eye movement and oculomotor control trainings studied in existing literature. Section 3 comprehensively explains the design and implementation of all the stages available in our application. This is followed by the discussion and user evaluation (section 4) and the conclusion (section 5).

Related Works (2)

One of the symptoms of AMD is the gradual increase of central scotomas (blind spots). It follows that patients will increasingly rely on their peripheral vision (sight outside the central field of vision). The progression of scotoma can cause various difficulties for patients in their daily lives. For example, a study conducted by Taylor et al. (2017) shows that patients will experience limitations in their visual search and scanning abilities (Taylor, 2017). Their study examines how patients perform visual searching in computer-based "real-world" and "everyday" tasks such as identifying a street name on a photograph and pointing at a landmark on a map among others. In a similar study by Higgins et al. (2020), patients take longer to visual search everyday objects and identify road signs (Higgins, 2020). Not only does AMD decrease the aforementioned visual abilities, but it also lowers the patients' reading rates. In patients with central scotomas, the patients' reading rates can range between 20 to 50 words per minute or lower. This is at least one-third the rate of the control group (i.e. those without AMD) (Seiple, 2005).

To counter these problems, Seiple et al. (2005) developed a variety of eye-movement control training exercises that were able to increase reading speed among AMD patients (Seiple, 2005). These exercises, for example, involve preset and random searches and letter and word

identification on a moving window among others. One of the key contributions of this work is that even though the exercises do not primarily involve direct practice in reading sentences, they are able to help increase reading speed by focusing on eye position and movement practices. In a later study, Seiple et al. (2011) examined various training module types and found that a curriculum like the ones developed by Seiple et al. (2005) are most effective at increasing reading speed among patients with AMD when compared to other rehabilitation modules (Seiple, 2011).

Design and Implementation (3)

MAC-U-Vision is organized into three stages, each corresponding to a stage of AMD. Additionally, all users can use the connecting and the scotoma tracking feature while having access to the stage-specific features and implementation depending on their disease stage and progression.

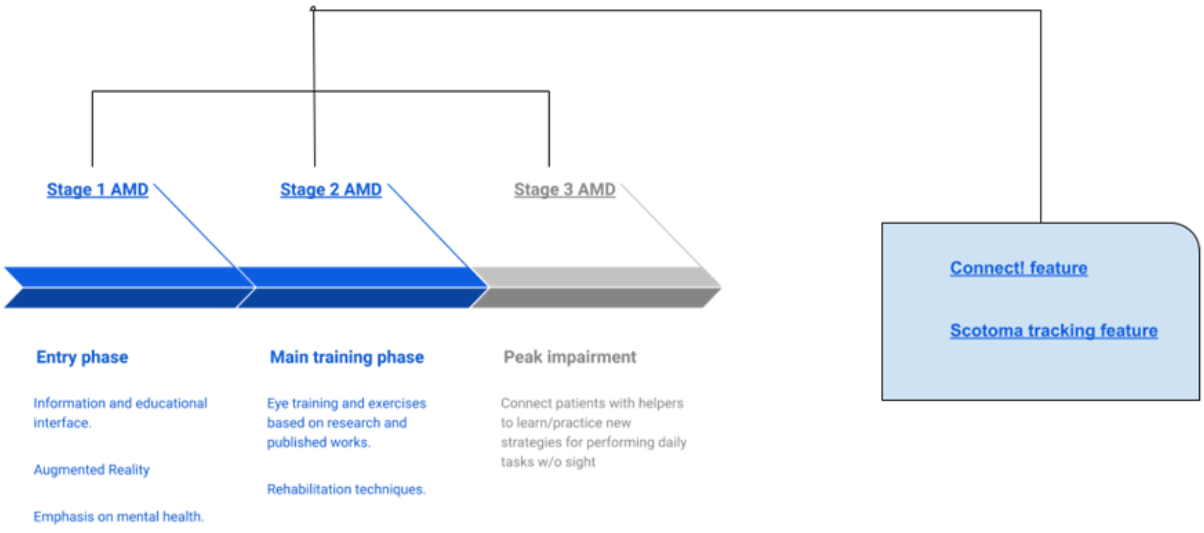

Fig. 1: Layout and organization of the major features in MAC-U-Vision.

A. Stage 1 (Educational interface and augmented reality)

Stage 1 is aimed at helping patients cope with emotions that may appear and help family members develop understanding for the patients.

Educational Interface

We implemented several information pages to help patients understand the disease better. For example, we created pages for *what to expect, how previous patients have coped with AMD, and what you can do to slow impairment.* The contents of these pages include texts, images, and videos.

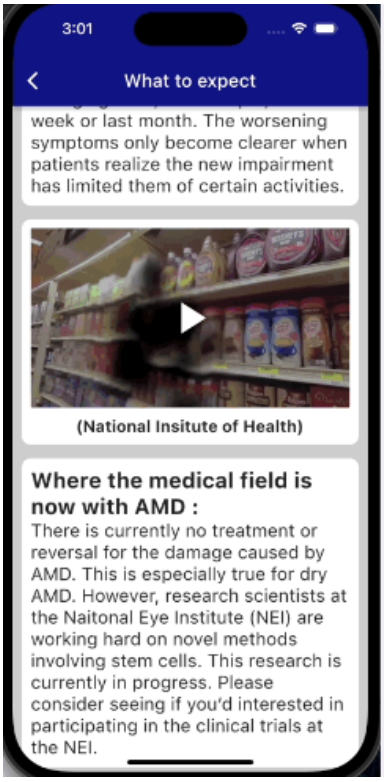

Fig. 2: Sample page of the educational interface.

Adaptation of augmented reality (AR)

We integrated an adaptation of AR technology via Unity into our platform. Users, in real-time, are able to move their cameras around to simulate what it is like to have AMD and central scotoma of varying intensities. A dark blind is placed at the center of the camera – it can also be adjusted to varying sizes where the largest one would be for simulating the later stage of the disease when the central scotoma is the largest as well.

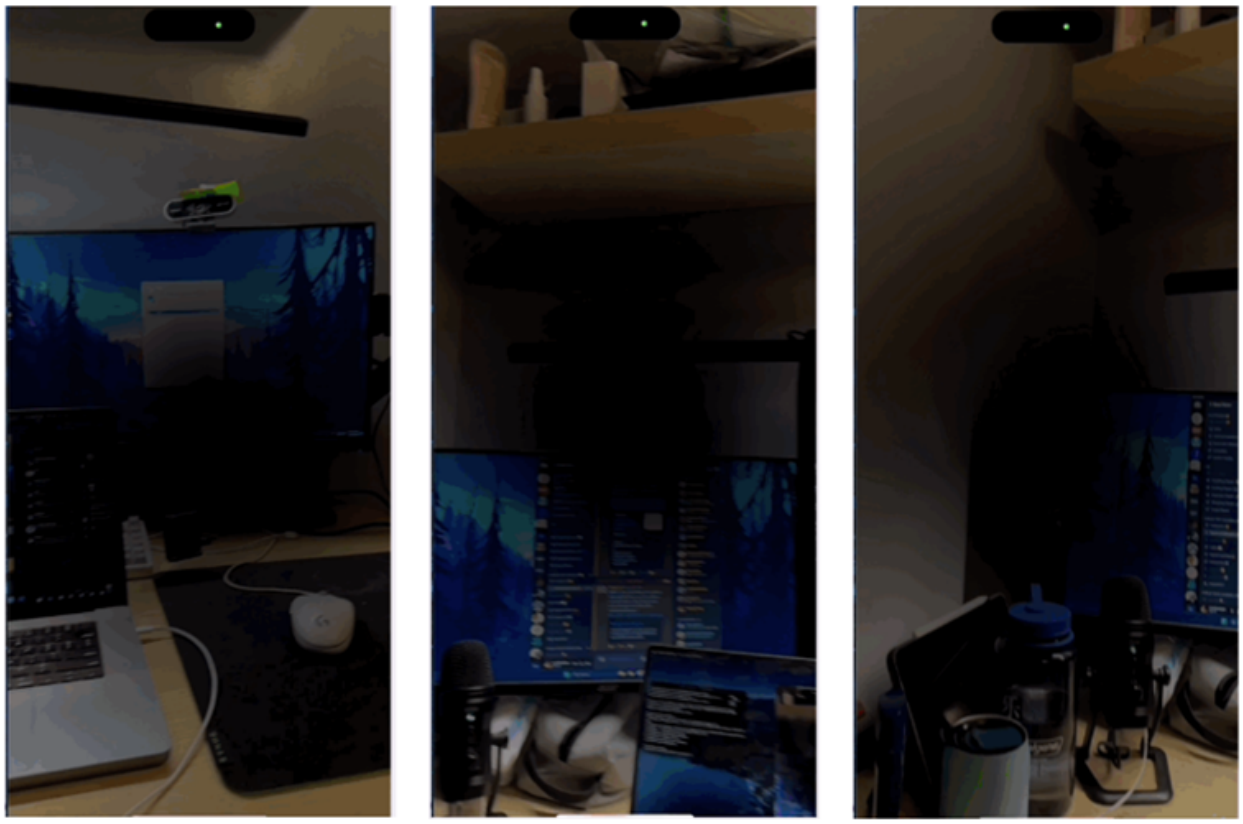

Fig. 3: AR implementation used as part of the educational interface in Stage 1.

Page listing support groups and referrals

AMD affects a large number of the elderly population, so there are existing support groups to help new patients cope and adapt. This includes support groups at both Lighthouse

Guild and beyond. A list of these are carefully selected and placed on a single page in the application.

B. Stage 2 (Eye & oculomotor control and rehabilitation trainings)

Stage 2 focuses on eye movement and oculomotor control training. Section 4 (Discussion and User Evaluation) further elaborates on their research values and how they were chosen.

Clockwise training – In this training set, small dots are arranged in a clock pattern with a larger dot at the center of the screen. Patients sequentially search and point/click the dot in a clockwise pattern – a dot disappears when it is touched. The timer starts the moment the patient touches a dot and stops when all the dots disappear.

Scattered training – This training is similar to the clockwise training. However, instead of presenting the dots in a specific pattern, the dots are now scattered across the screen. Patients continue to record their time performance.

Eccentric fixation chart - In this section, users can use the chart to explore where their "sweet spots" - i.e. the area in their field of view where they can see best - are. The chart contains letters that are organized in circular patterns (total of 3).

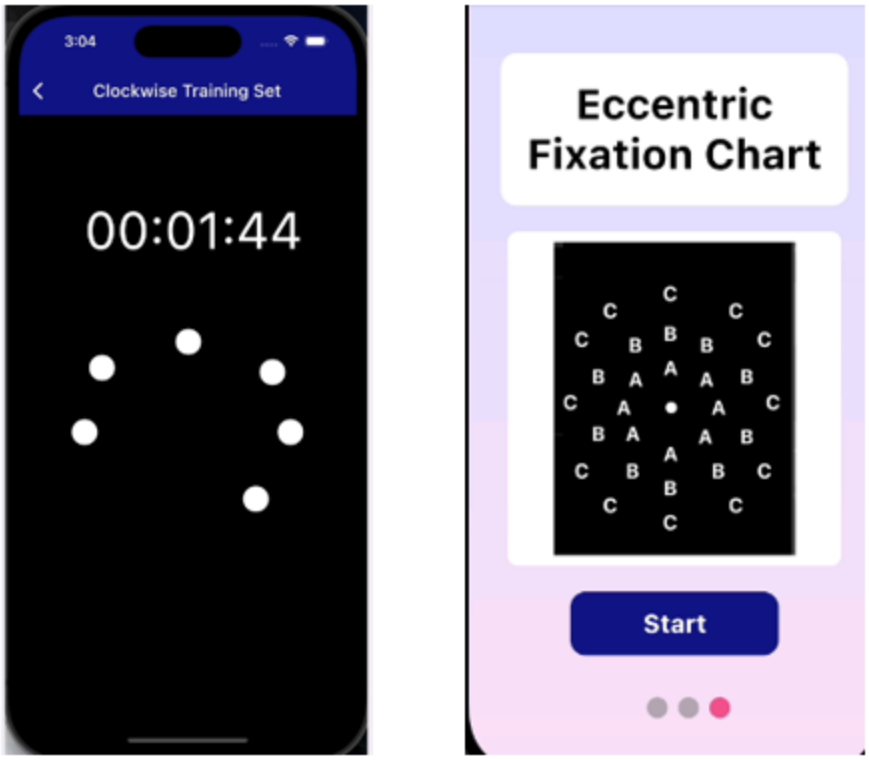

Fig. 4: (a) Clockwise training and (b) eccentric fixation chart.

C. Assisting at the last stage (networking)

Discussion forum - The discussion forum serve as a networking and connecting spot for patients, helpers, and family members.

Fig. 5: Discussion forum sample.

D. Features for any stage

Scotoma tracking feature

We will use the eccentric fixation chart as the basis to track scotoma progression over time. Patients can use the scotoma progression tool by pointing to where blind spots are in their visual field. This feature will be a self-progression tool for users to track their vision over time (weeks/months)/ This feature is currently under development.

Text-to-speech - To ensure accessibility for the patients, we have a text-to-speech feature that use the white box method to represent a piece content made available by audio. Users can press and hold to turn the content into audio.

Discussion & User Evaluation (4)

To assist at the first stage of AMD, where patients have minimal to mild loss of vision and usually near the time of diagnosis, we focused on the patient's mental health and informational practices. During the literature review phase of our research, our initial interviews with two patients (83yo M and 71yo F) suggest that they were most vulnerable to depression at this stage and, at first, did not fully understand the disease and how it progresses. Therefore, we implemented the educational interface, connect feature, and referrals to low-vision mental health providers to tackle the aforementioned concerns. The purpose of the AR is to also further teach patients about the progression of AMD and what vision could be like if the disease progresses. AR, additionally, can also raise awareness of AMD for the general public and, more importantly, help patients' family members develop an understanding and compassion for the patients.

And while the connect feature is available for use throughout all the stages, patients may find the discussion forum and the chat the most helpful in the first stage, as they are geared toward helping patients cope mentally and connect with other patients who had the same experience before during diagnosis. Additionally, patients can also utilize our scotoma tracking feature, which is designed to track the progression of the disease in the long-term (scale: months and years). This will not only help family members understand the current symptoms but the patient's ophthalmologist and optometrist may also find such information helpful.

To assist at the second stage of the disease, where patients experience moderate vision impairment and larger drusen, we incorporated eye training and exercises. Since patients with AMD have difficulty reading because the disease decreases the eyes' ability to scan, we implemented trainings that target the patients' eye movement with the goals of improving search efficiency and increasing reading speed. These training, such as the preset clockwise and scattered search among others, are adaptations of and based on the study conducted by Seiple et al. (2005). Seiple et al. found that the (original) preset-search task, for example, improved the response time of patients. On the first trial, patients had a response time of 1640 ms on average. This decreases to 1347 ms on the last trial (16 patients, 65-87 years, mean = 77 Y) (Seiple, 2005).

Moreover, since one of the goals of our application is to remain with the patients throughout the disease progression, we specifically designed a training module that requires minimal external equipment. In our initial interviews, patients have previously bought assistive equipment such as a headset. But after months and years, such equipment is no longer compatible with the patients because the disease has progressed. Hence, our training module is primarily non-eye-tracking and does not require external tools or accessories.

The third stage of AMD is the most difficult to design a solution idea primarily because this is when patients would have already lost their central vision entirely. We included basic features that connect patients with helpers to learn and practice new strategies for performing daily tasks without sight. This stage requires the most involvement from the community compared to other stages, which is one of the reasons why we also initially designed our platform to be usable by the general public and family members among others to help raise awareness and develop understanding.

Patient	Age (y)	Sex	Cause of vision loss
1	54	F	MD, glaucoma
2	83	M	MD
3	-	-	MD, retinal atrophy
4	-	-	MD
5	-	-	MD
Mean		-	-

Table. 1: Characteristics of patients that participated in our study. (MD = macular degeneration). There are 3 patients we plan to interview in the coming weeks.

To perform user evaluation, we informed the patients about the goals of our application and allow them to spend time on the application. We then ask the patients several questions we prepared on the questionnaire. We have a list of 5 patients total that we will include in the URTC manuscript. For the final project, we are including the first two (54F and 83M). We have received positive feedbacks and support from both patients as they find many of our implemented features useful. For example, the 83M patient reported that he finds the eccentric fixation helpful for finding his sweet spot. The eccentric fixation chart contains letters organized in a circular pattern. He was able to take advantage of the letter cluster to find where his vision is the clearest and least blind spot for reading texts. During the clockwise and scattered training sets, the patients have several incorrect taps and report that the trainings are good at helping them train their eyes to correctly focus on the dot saccade. Both patients had trouble seeing the button bars and cannot read the texts on the app as a result of the disease. Patients can see text blocks but cannot interpret the words. However, this problem can be resolved using our text-to-speech feature that reads out the text to patients upon being tapped on. The phase where they need most assistance would be the initial registration. Although login information can be saved for future

sign-ins, the initial registration may require external helps as new users would have to manually type in their email and set their password.

Potential Markets and Branding (5)

The demographic of our target market will consist of elderly people, in particular those that are above the age of 40 years old. As we have discussed previously, AMD is the leading cause of vision loss, affecting up to 11 million people in the United States alone. In 2006, it was estimated that 4.1% of New Yorkers over the age of 40 years old were affected by AMD. We can estimate this number to be around 350,000 through 400,000 given the population data in 2006 being just under 9,000,000 for people aged 40 and over. However, this was over 15 years ago. Over time we have seen an increase in cases and is even expected to double over the next few decades. This means that we can very well expect to see the number of people affected to reach over a million people, and that's in New York State alone.

As we scale our business and impacts, we will continue to target our service for AMD patients in the US and beyond. By 2050, existing research projected that AMD will affect up to 22 million people in the US alone. On the global scale, there are estimates that almost 9% of people with age over 45 will be diagnosed with AMD of some form, which is a total of approximately 196 million people. Since we focus on software, the distribution will also be easier provided users have a mobile phone or tablet and access to the internet.

In our logo and icon, we aim to use colors that represent trust and nurture, which are important when interacting with patients. The bold font is designed to be visually accessible with maximal contrast, making it easier for the patients to see and focus. Additionally, we have an eye with the pink heart in our logo to represent our app's goal of assisting AMD patients emotionally

and mentally, spreading awareness of the disease, and encouraging family memebers to develop empathy and compassion for the patients.

Figure 6: App and logo of the platform.

Conclusion (6)

MAC-U-Vision aims to provide progressive training and assistance for AMD patients throughout all the stages of the disease. By organizing the platform into multiple stages, each tackling a stage of AMD, we can enhance the livelihood of patients at their current stage of the disease, help patients prepare for more vision loss that may occur as the disease progresses, and support patients emotionally – which are our primary contributions. Our work helps fill the gap that most technologies are primarily assistive technologies or aimed to help those who are already blind or those whose vision is severely affected.

As for future work, not only do we plan to incorporate more eye movement and rehabilitation trainings into our study but we also want to extend the features by using an external eye tracker. Using an eye tracker will be part of the study on feedback loops for patients. That is, the eye tracker can help the app inform the patient of how the patient can, for example, correctly point to a dot saccade in the training. This feedback loop system has been studied in optometric research and can be beneficial to implement in our platform.

Acknowledgment

The work in this project is our own. Any outside sources have been properly cited. This project is supported by the CCNY CEN Course Innovation Grant. We are grateful for the patients and participants at the Lighthouse Guild (names omitted for patient privacy) who provided direct feedback and served as user evaluations throughout the development of the project. We also thank Ms. Fernanda N. Garcia-Pina for helping coordinate patients contacts. We would also like to thank external participants who provided feedback through our surveys.

References

[1] Klein R, Klein BE, Jensen SC, Meuer SM. The five-year incidence and progression of age-related maculopathy: the Beaver Dam Eye Study. Ophthalmology. 1997;104:7–21.

[2] Prevalence Estimates | Vision and Eye Health Surveillance System | Vision Health Initiative (VHI) | CDC

[3] Taylor DJ, Smith ND, Crabb DP. Searching for Objects in Everyday Scenes: Measuring Performance in People With Dry Age-Related Macular Degeneration. Invest Ophthalmol Vis Sci. 2017 Mar 1;58(3):1887-1892. doi: 10.1167/iovs.16-21122. PMID: 28358960.

[4] Higgins BE, Taylor DJ, Bi W, Binns AM, Crabb DP. Novel computer-based assessments of everyday visual function in people with age-related macular degeneration. PLoS One. 2020 Dec 7;15(12):e0243578. doi: 10.1371/journal.pone.0243578. PMID: 33284855; PMCID: PMC7721163.

[5] Seiple W, Szlyk JP, McMahon T, Pulido J, Fishman GA. Eye-movement training for reading in patients with age-related macular degeneration. Invest Ophthalmol Vis Sci. 2005 Aug;46(8):2886-96. doi: 10.1167/iovs.04-1296. PMID: 16043863.

[6] Seiple W, Grant P, Szlyk JP. Reading rehabilitation of individuals with AMD: relative effectiveness of training approaches. Invest Ophthalmol Vis Sci. 2011 May 5;52(6):2938-44. doi: 10.1167/iovs.10-6137. PMID: 21296824.

Team Members:

Alan Tepoxtecatl [+3 dominant contributor] (Role: Principal Software Engineer) - AT is the lead software engineer and oversees the software development and technology implementations of the project.

Crystal Yang [+3 dominant contributor] (Role: Principal Frontend Developer) - CY is the team's lead designer and software engineer. CY oversees the UI, frontend, and marketing aspects of the project.

Max Sehaumpai [+3 dominant contributor] (Role: Principal Investigator) - MS is the team's research associate and is the primary and corresponding author.